Earth Sciences Report 80-2

Hydrogeology of the Steen River-Whitesand River Area, Alberta

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Alberta
RESEARCH COUNCIL

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ABSTRACT

This report describes the hydrogeology of the uppermost 300 m (1000 ft) of strata in the Steen River-Whitesand River map area. The maps and profiles were constructed from existing data and information collected in a field survey. Evaluations of geology, topography, groundwater, and surface water chemistry were fundamental in estimating hydrogeologic characteristics.

The 20-year safe yields for half the area are over 0.4 L/s (5 igpm) and only for a small area of very thick drift with buried gravel beds are they more than 8 L/s (100 igpm). The only practical aquifers are those within the drift. The drift in the westernmost quarter of the area is thick and contains several sand and gravel aquifers. Potential aquifers in bedrock are the Dunvegan sandstone with a yield of 0.4 to 2 L/s (5 to 25 igpm), and perhaps the near-surface part of the Devonian limestones in their subcrop area in the north-central part of the map area.

The quality of shallow groundwater in drift aquifers is good over most of the area. The total dissolved solids content is usually less than 500 mg/L and the water is a calcium bicarbonate type. In small areas, especially along the slopes and deep valleys of the Caribou Mountains, a calcium sulfate type of groundwater is found with a total dissolved solids content of up to several thousand ppm. The quality of water in bedrock aquifers is very undesirable. Calcium or sodium sulfate water is present at moderate depths (from 60 to 180 m, 200 to 600 ft) and sodium chloride at greater depths (from 120 to 425 m, 400 to 1400 ft). The total dissolved solids content is high, several thousand or several tens of thousand and occasionally near 300 000 mg/L.

INTRODUCTION

The Steen River (84N) — Whitesand River (840) map area, in northern Alberta between longitudes 114° and 118° west and latitudes 59° and 60° north in Tps 115-126, Rs 1-24, W5 Mer, covers about 25 030 km^2 (approx. 9660 sq mi). When this study was completed, only 1:63 360 (1 in:1 mi) planimetric maps were available for the area.

From a field survey carried out in 1977, mainly by helicopter, hydrogeological maps and profiles of the area were constructed during 1977-78. The legends of these maps follow the one for the Alberta Hydrogeological Reconnaissance Series (Badry, 1972) and are based on international usage.

Some data about surface waters were published by Reeder *et al.* (1972) and Inland Waters Directorate (1976).

Access to the area is difficult. The westernmost region is crossed by the Mackenzie Highway (presently under improvement) from which a gravelled sideroad branches out to Zama Lake. Most of the area is without roads. Although the area has some forestry airstrips, most of it can be reached only by helicopter.

The area is nearly unpopulated. The only settlement of mention is Meander River (population 233 in 1977; Alberta Business Development and Tourism, 1977), which has two gas stations with motels and some forestry buildings. The area includes the Meander River Indian Reserve and part of Wood Buffalo National Park.

The vegetation of the area is mainly aspen poplar and spruce (both black and white) or lodgepole pine forests. The plateau of the Caribou Mountains has treed muskeg (sphagnum moss and black spruce). Some areas have several kinds of conifer forests, willow-aspen scrub, and northern wetland grass (Government and University of Alberta, 1969).

Little industrial activity is currently in the area, except for some lumbering, although some hydrocarbon prospecting is taking place and some natural gas is being developed.

ACKNOWLEDGMENTS

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The assistance of the Footner Lake Forest Office in establishing aviation fuel caches and especially the kindness of J.M. Skrenek and J. Graham are gratefully acknowledged. The Hudson's Bay Oil and Gas Co. Ltd. and Chevron Standard Ltd. provided unpublished data. Field notes and observations of the geology of the area were made available by R. Green of the Alberta Research Council. Assistance in data collection was ably given by M. Wollen. F. Tuck edited the report.

TOPOGRAPHY AND DRAINAGE

The map area lies within the Interior Plains and includes parts of the Alberta High Plains (Cameron Hills Upland, Caribou Mountains Upland, Fort Nelson Lowland) and the Great Slave Plain (Hay River Plain) physiographic regions (Government and University of Alberta, 1969, p. 9). The physiographic units are shown on the chemistry side map.

The highest point in the area, about 1020 m above mean sea level (3350 ft amsl), is located in the Caribou Mountains. The lowest point of the area is where the Hay River leaves, about 290 m (950 ft) amsl. Consequently, the maximum difference in elevation within the area is about 730 m (about 2400 ft).

The topography includes plains and undulating plateaus with more or less steep-sided slopes. Since the entire area was covered by the Wisconsin ice-sheet, the landforms are mostly glacial (Lindsay *et al.*, 1960). The plateau of the Cameron Hills is heavily fluted. Ice-disintegration features (Gravenor and Kupsch, 1959; Stalker, 1960) are widespread. Areas of glaciofluvial and glaciolacustrine deposits are also present. In the lowlands, the rivers meander and oxbow lakes characterize the alluvial floodplains.

A regional set of old, more or less stabilized, slump features characterize the slope of the escarpment of the Caribou Mountains. Elongated lakes, ponds, or wet meadows formed between the slump blocks and scars are often situated in sequence up the slope. The regional slump system encircling the Caribou Mountains is the best example of its kind in Alberta. Within the map area, the slump system extends north and east from the Yates River along an arch of 125 km (80 mi). The Yates, Whitesand, and Buffalo Rivers and their tributaries, which cut deep valleys into the escarpment of the Caribou Mountains, show numerous active slumps on their steep valley slopes.

The entire area belongs to the Mackenzie River-Arctic Ocean drainage system. The three main sub-basins within the area (Fig. 1) are the Peace River, the Great Slave Lake (excepting the Slave River watershed), and the Mackenzie River (below its outflow from the Great Slave Lake) through the Liard River. The watersheds of some important tributaries are also separated on the attached hydrogeological map.

Of the many lakes in the area, the largest is Wentzel Lake, of which about 36 km^2 (14 sq mi) lie within the area.

Much of the area is covered by muskeg. Ribbed fens formed by parallel, low (0.5 to 1.5 m, 2 to 5 ft high) ridges of peat and narrow, wet depressions right angles to the direction of drainage (Sjors, 1963; Zoltai, 1971) are widespread.

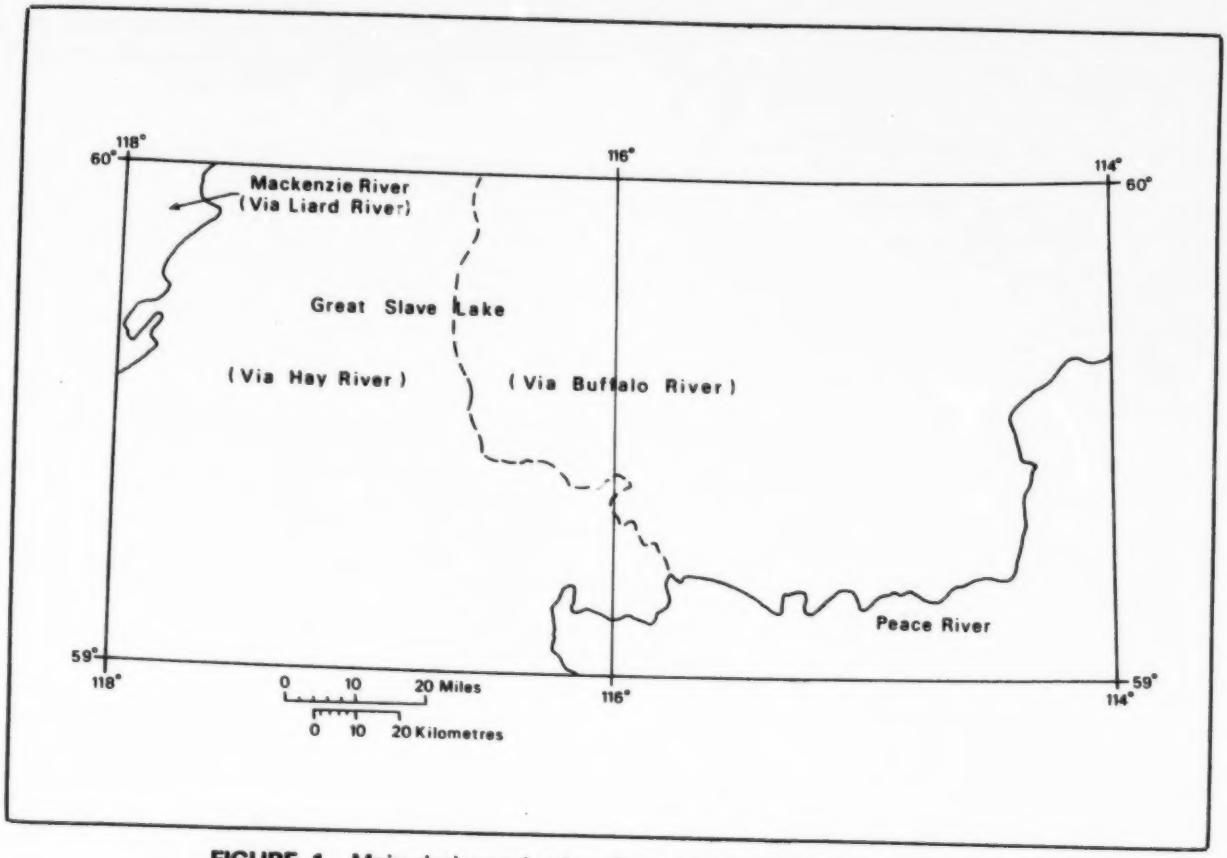

FIGURE 1. Main drainage basins, Steen River – Whitesand River area

CLIMATE

The entire area, in the "short, cool summer" (Dc) Koeppen zone (Longley, 1972, Fig. 53), is within the zone of the discontinuous permafrost and has been described as the "southern fringe of permafrost region" by Brown (1967) and as "permafrost area for organic soils" by Lindsay and Odynsky (1965).

Isohyets (slightly modified to fit orography better) after Longley (1972, Fig. 47) are shown on the meteorological side map. Four summer rain gauges were in service in the area from May to September (in one case to August) (Stashko, 1971). Precipitation for October (or September as the case may be) to May was calculated by the same rate as was observed at the nearest meteorological station (Ft. Vermilion). Unfortunately, these rain-gauge observations are available only for a few (2 to 8) years. Because of the short observation period, summer rain-gauge data are shown on the side map as specific information, but have not been used to modify the isohyets. Elevated areas receive between 406 and 457 mm (16 and 18 in) and the valley of the Hay River somewhat below 406 mm (16 in) of precipitation.

Snow covers the area from the end of October to the end of April (Potter, 1965, charts 2 and 5). At Fort Vermilion, near the map area, the mean temperatures are: −23.1°C for January, 16.5°C for July, and −1.6°C annually (Canada Department of Transport, 1967). The potential evaporation (estimated from maps constructed by Bruce and Weisman, 1967) exceeds precipitation as an annual mean and also during each month from May to October.

GEOLOGY

BEDROCK GEOLOGY

The bedrock geology of the area, represented on a 1:1 000 000 scale side map and on the four profiles to a depth equal to the mean sea level, was constructed from borehole data, electric logs, lithologs, and the published literature (going back to Cameron, 1922). Most data were generated by oil prospecting drilling or geophysical operations that did not, however, extend into Wood Buffalo National Park. Bedrock outcrops are limited to stream cuts and slump scars.

The geological side map is based primarily on the map of "Bedrock geology of northern Alberta" (Green *et al.*, 1970) which shows rock-unit boundaries projected to the surface. Boundaries on the present geological side map are, however, subcrop boundaries. The two types of boundary presentations show substantial differences where drift cover is thick such as in the Cameron Hills, at the western slopes of the Caribou Mountains, and in the north-central portion of the plain lowland area.

The oldest rocks (in a position higher than the mean sea level) in the area were only in the Steen River structure in the west-central part of the area. The Steen River structure is characterized by a high Precambrian crystalline basement, and is the only known presence in the map area of plutonic, volcanic, shock-metamorphic, and Mississippian sedimentary rocks. The structure is most likely a crater created by an early Cretaceous shock: a meteorite impact or an intracrustal explosion (Carrigy, 1968). The shape and boundary of the structure shown on the side map is conjectural.

The oldest rocks shown on the profiles are Middle and Upper Devonian marine (occasionally evaporitic) sediments:

- Beaverhill Lake (and Slave Point) Formations, limestone, some evaporites;
- Hay River (and Ireton) Formations, shales, and at places partly limestone;
- Woodbend Group, limestone, with dolomite and shale;
- Winterburn Group, silty limestone, sandstone, and dolomite, some anhydrite;
- Wabamun Group, limestone and dolomitic limestone.

The geological side map shows the structure contours on top of the Devonian formations [modified from the Energy Resources Conservation Board (1963) map]. The contours are smoothed somewhat because the discordant upper boundary of the Devonian complex (the Pre-Cretaceous erosion surface) is uneven, undulating, at places karstic or tectonically controlled, and likely contains closed depressions. The Devonian beds dip southwest at a little less than 1 m/km (5 ft/mi). The boundary surfaces between the different Devonian units also dip to the west and south but more steeply; reef development is also involved. The lithology of the Devonian formations immediately below the Pre-Cretaceous erosion surface is mainly limestone in the western two-thirds of the area, while it is shale in the east; the side map shows their boundary. Woodbend and Winterburn limestones in the north-central and Hay River shales (possibly with some limestone beds) in the north-eastern part of the area form subcrops under a blanket of drift.

The tectonics of the Devonian complex (mainly block faulting) are simplified on the side map. The block faulting of Devonian rocks may or may not influence the overlying younger beds; to construct the A-A' profile the first working hypothesis was used (for the B-B' profile, the second one was used).

The Bluesky-Gething Formation follows the dip of the erosion surface; other Cretaceous units have more gentle dips or are nearly horizontal. The Cretaceous units, represented on the map and/or the profiles, are listed below; parts of the formation descriptions (in italics) are provided by Green *et al.* (1970).

Bluesky-Gething Formation (Lower Cretaceous): 3 to 30 m (10 to 100 ft) thick sandstone, silty sandstone, and shale deposited over the Pre-Cretaceous erosion surface and into its depressions; mainly non-marine. The conjectured extent of the Bluesky-Gething Formation and structure contours on top of the formation are shown on the side map.

Loon River Formation (Lower Cretaceous): *dark grey fossiliferous silty shale and laminated siltstone, ironstone nodules and partings; marine.* This formation is 180 to 250 m (600 to 800 ft) thick

under the uplands, but is thinner in the lowlands because of partial erosion. The Loon River Formation is the oldest known to outcrop in the area.

Shaftesbury Formation (Lower and Upper Cretaceous): *dark grey fish-scale bearing shale, silty in the upper part; numerous nodules and thin beds of concretionary ironstone; bentonite partings; interbedded locally in lower part with silty and sandy intervals; marine.* This formation is about 210 to 250 m (700 to 800 ft) thick in the Caribou Mountains; thinner and erosionally dissected in the Cameron Hills. The Base of the Fish Scales marker horizon, regarded as the boundary of the Upper and Lower Cretaceous, divides the Shaftesbury Formation approximately in half in the Caribou Mountains. A structure contour map of the Base of the Fish Scales is available from the Energy Resources Conservation Board (1969).

Dunvegan Formation (Upper Cretaceous): *grey fine-grained feldspathic sandstone with hard calcareous beds, laminated siltstones and grey silty shale; deltaic to marine.* This formation is only in the Caribou Mountains; its uneroded thickness is about 125 m (400 ft).

Smoky Group equivalent (Upper Cretaceous): dark grey shale in the Caribou Mountains, which have eroded into several separate blocks; marine. The maximum thickness is about 125 m (400 ft).

BEDROCK TOPOGRAPHY AND SURFICIAL GEOLOGY

The drift cover of the area is very different from place to place both in thickness and lithology. The Cameron Hills are covered by thick, uneven drift; from about 170 m (550 ft) in one hole to, it is conjectured, nearly 400 m (1300 ft) in a buried channel. In the lowland area and the western slopes of the Caribou Mountains, the drift is 15 to 45 m (50 to 150 ft) thick, and is usually less than 30 m (100 ft) thick in the Caribou Mountains. The drift cover is very thin over the Devonian limestone subcrop in the north-central area and over the northern-northeastern slopes of the Caribou Mountains.

The bedrock topography of the area is represented on a 1:1 000 000 scale side map constructed from interpreting electric logs, air-photographs, space imagery, lithologs, and surface observations. The conditions of the Cameron Hills were adopted from the manuscript map of R. Green with some modifications in the central portion. Both the available data and the small scale of representation preclude presenting fine details of the bedrock topography on the side map. The buried, erosional topography with bluffs, gullies, and deep valleys is vivid both in the Cameron Hills and in the lowlands. The bedrock topography of the northern slopes of the Caribou Mountains is a near replica of the present surface, apart from areas of heavy slumping.

The surficial geology of the area is known only in general. An unpublished manuscript surficial geology map of 1:250 000 scale by L. Bayrock (then of Alberta Research Council) covers the northeastern quarter of the area.

A Tertiary gravel cap is mentioned from the Caribou Mountains by Bayrock (*in* Lindsay *et al.*, 1960). Pre-Pleistocene unconsolidated sediments are also likely present at the base of the thick drift in the Cameron Hills, especially in the buried valley. There are gravel deposits along the terraces of the Hay River (the valley originated as a large glacial spillway). Several horizons of fluvioglacial sand and gravel were encountered during drilling in the thick drift of the Cameron Hills. The plateau of the Caribou Mountains contains gravel kames. Bed moraine till is widespread over the area. The lowlands have extensive areas of fluvioglacial lake deposits with variable lithology of sand, silt, clay, and rafted debris (Bayrock, *in* Lindsay *et al.*, 1960).

Peat and organic soils, which may exceed 6 m (20 ft) in thickness in the Caribou Mountains, are found in patches of different thickness throughout the area.

HYDROGEOLOGY

DATA USED IN MAP PREPARATION

Data used to construct the maps and profiles (altogether 420 data points) are shown on the data density and chemistry side maps. The distribution

of the geological and hydrogeological data is uneven. Within the Wood Buffalo National Park, sources of data were mainly restricted to observation and sampling surface phenomena.

The scale of the hydrogeological map, 1:500 000, is best suited to the available data and local topography. The same scale was used for most of the reconnaissance hydrogeological maps of northern Alberta.

GROUNDWATER LEVELS AND FLOW SYSTEMS

Groundwater level contours were not constructed due to insufficient data. Characteristic flow lines drawn on the profiles and represented on the map are inferred from chemical and pressure conditions, lithology of the aquifers, and topography.

Muskeg or wet soil covers a considerable part of the map area, including hilltops, plateaus, slopes, and valleys, indicating that the water table is very near the surface. Although locally this shallow water table may be only that of a perched water body, the abundance of muskegs indicates a degeneration of flow systems in those areas resulting from extended periods of soil frost. In this case, most groundwater moves in the upper 1 to 3 m (3 to 10 ft) of the soil, mostly in organic deposits, and is mainly parallel to the surface, in contrast to the steeply descending and ascending limbs of normal flow systems of groundwater. The elongated crescents of ribbed fens or other solifluctional phenomena can often be seen on the surface.

DISCHARGE FEATURES

The area has only a few typical springs, that is, point-like concentrated groundwater discharge sites in the area. Groundwater discharge in the area is diffuse: for example, groundwater contributes to moving or stagnant bodies of surface waters (streams, lakes, muskegs) and is consumed by phreatophytic vegetation. Pooled and submerged springs form a transition towards ponds and lakes fed by groundwater.

Common semi-diffuse discharge features of the area are quasi-springs: muskegs with an outflow or springs masked by muskeg. Water from these sources is usually low or very low in dissolved salts (50 to 300 mg/L). Nitrate might be an important anion in the waters with very low dissolved salt content; cation-anion imbalance may point to organic acids and colloides.

Slumps are widespread in the area. The regional slumping encircling the Caribou Mountains is currently more or less inactive. Along the deep, steep-walled valleys, however, active slumps are numerous. Groundwater discharge conditions usually contribute to slumping. Discharging groundwater often seeps, trickles, or flows from the slump scars or the fragmented moving rock mass; these sites can be considered special kinds of springs. Behind the slump block, a surface depression is created in which a pool of water (temporary or permanent) can often be found. This pool or backpond can be fed by groundwater, precipitation, surface water, or any combination of the three.

Slumping promotes oxidation of the mineral content of the rocks because it breaks up the beds, exposing the enlarged surface of the fragments to the air or to oxygen-rich water or to both. The dark shales and tills of the area contain abundant sulfur under low redox potential circumstances. Slumping in these rock materials results in sulfur-oxidation; the discharging water is rich in sulfates. Mineral precipitates may be on the surface and in the joints, cracks, and cleavage of the slumping or exposed shale. The mineral precipitation of a slump site, some kilometres east of the eastern boundary of the area was determined by D. Scafe of the Alberta Research Council as hexahydrite ($MgSO_4 \cdot 6H_2O$). The groundwater outflow from the slump sites may be secondarily enriched in mineral content by dissolving such precipitates. Water in pools and backponds also becomes more dense by evaporation. Some examples of these different types of groundwater discharge features are given below.

The best-developed spring in the area is in the valley of the Dizzy Creek, on the western marginal part of the Caribou Mountains, in Lsd 13, Sec 31, Tp 117, R 13, W5th Mer, at an altitude of about 780 m (2550 ft) amsl. The spring site is on the right bank of the creek on a small terrace fragment being

undercut and destroyed by a meander: the terrace material slumps in small blocks into the water. The spring originates at the foot of the steep slope of a 10 m (30 ft) high sand and gravel terrace, which is covered by pine forest. The yield of the spring at the time of observation (August 1, 1977) was about 0.8 L/s (10 igpm) and its temperature was 7°C. The relatively high, summer temperature in the case of a freely flowing, fresh spring suggests a short, shallow flow path. Groundwater feeding the spring must mainly recharge within the area of the higher sand and gravel terrace, which is consistent with the chemistry of the water: low total dissolved solids content (146 mg/L) and a calcium bicarbonate type.

An example of a spring on the plains is on the left bank of Tourangeau Creek at the outermost point of a meander, in Lsd 8, Sec 4, Tp 126, R 8, W5th Mer, at an altitude of about 310 m (1020 ft) amsl. The spring forms a 10 m (30 ft) diameter, reddish-brown, iron hydroxide film-covered pool with a water level near that of the creek. The yield was about 0.4 L/s (5 igpm) and the water temperature 17°C on August 4, 1977. The high temperature was likely due in part to warming in the pool and partly because bank storage of the creek water contributed to the spring. Both the alluvium of the creek and the bed moraine drift of the surrounding plain contain much silt, which is reflected in the chemistry of the springs: 210 ppm total dissolved solids and a calcium-sodium bicarbonate-chloride type of water (no single ion is more than 60 percent).

A spring at the northern foot of the Caribou Mountains is actually hidden under the water of an oxbow lake in the valley of a creek, in Lsd 6, Sec 2, Tp 123, R 5, W5th Mer, at an altitude of about 500 m (1650 ft) amsl. The oxbow is in a bed of boulders and gravel, while the drift of the surrounding area is bed moraine. The underlying bedrock is the lower part of the Shaftesbury Formation (shale, interbedded with silty and sandy intervals). Water exchanged between the oxbow lake and the creek is seepage through a gravel bar which separates them. The water of the oxbow is greenish grey and clear, has a temperature of 18.8°C (on August 5, 1977), contains 566 mg/L total dissolved solids, and has a calcium sulfate chemical character. The relatively high dissolved solids content (four times that of the creek) and high sulfate ratio (66.6 percent anions) in the absence of rocks fragmented by slumping indicate that groundwater from bedrock aquifers feeds the oxbow. The warm temperature must be a consequence of the warming of the unshaded pool of water in the summer weather.

An example of a pond fed by groundwater in Lsd 15, Sec 7, Tp 126, R 12, W5th Mer, at an elevation of 300 m (980 ft) amsl, has a surface outflow but no surface inflow. The water has a total dissolved solids content of 248 mg/L, is a sodium-calcium bicarbonate-sulfate type, and contains no ion in a ratio of more than 60 percent.

A quasi-spring in the Caribou Mountains, in Lsd 8, Sec 30, Tp 116, R 13, W5th Mer, at an altitude of 870 m (2860 ft) amsl, shows the characteristics of water moving only in organic materials. The water has a total dissolved solids content of only 108 mg/L and a calcium-magnesium nitrate character. Another quasi-spring, in the plain, in Lsd 10, Sec 15, Tp 117, R 24, W5th Mer, at an altitude of 350 m (1150 ft) amsl, shows more mature groundwater characteristics. The water originates from a ribbed fen, has 228 mg/L of dissolved salts, and is a calcium-sodium bicarbonate type.

The characteristics of the water discharging at slump sites depend on the host rock material. Three examples are given below: slumps in peat, in gravel and sand, and in shale.

A slump site on the plateau of the Caribou Mountains, on the undercut right bank of the Ponton River, in Lsd 15, Sec 28, R 10, Tp 115, W5th Mer, is at an elevation of about 815 m (2680 ft) amsl. The 6 m (20 ft) high wall is formed by dark grey Smoky shale and reddish-brown peat. A small trickle (0.1 L/s, about 1 igpm) of water drips from the peat and flows on the surface of the shale. The temperature was 7.1°C on August 2, 1977. The water contained 208 mg/L total dissolved solids and had a calcium sulfate character (85 percent of the total anions, epm, being SO_4^{-2}).

A 45 m (150 ft) high-walled, cirque-like slump in silty sand and gravel in the valley of the Berry Creek, on the western margin of the Caribou Mountains, in Lsd 8, Sec 21, Tp 117, R 1, W5th Mer, is at an altitude of about 665 m (2180 ft) amsl. Water discharges at about 0.4 L/s (5 igpm), is

muddy, yellowish-brown in color, and forms small pools and trickles. The trickle sampled had a temperature of 18.1°C (on August 6, 1977), a total dissolved solids content of 876 mg/L, and a calcium sulfate chemical character.

A slump in a deep stream cut in the northern slopes of the Caribou Mountains, in Lsd 8, Sec 23, Tp 122, R 6, W5th Mer, at an altitude of about 610 m (2000 ft) amsl has rock material of dark grey Shaftesbury shale. A yellow precipitate can be seen on joint and bedding surfaces within the shale. The sampled rivulet with a flow rate of about 0.8 L/s (10 igpm) comes from a backpond that receives a surface inflow and is not direct groundwater discharge. The sample contains 6438 mg/L total dissolved solids and is of a mixed cation sulfate character (that is, neither cation reaches 40 percent of the total cations, epm).

AQUIFER LITHOLOGY

The generalized lithology of each rock unit is represented on the hydrogeological profiles. The generalized lithology of the best aquifer within the uppermost 300 m (1000 ft) is shown on the main map.

GROUNDWATER PROBABILITY

The total available 20-year safe yield from the upper 300 m (1000 ft) is shown on the main map by color-coded areas. The 20-year safe yield of each rock unit is also shown on the hydrogeological profiles by a color code. These are both "possible" yields, estimated from qualitative information: lithology, electric logs, topography, and surface phenomena.

Yields of over 8 L/s (100 igpm) may be expected in a part of the Cameron Hills where the drift is very thick and contains portions of sand and gravel. Yields of 2 to 8 L/s (25 to 100 igpm) are predicted in the Cameron Hills (except on its slopes) and along the Hay River, from sands and gravels contained in the drift. Yields of 0.4 to 2 L/s (5 to 25 igpm) are predicted on the slopes of the Cameron Hills and in the central zone of the plains area from drift, as well as in the main plateau of the Caribou Mountains from sandstone beds of the Dunvegan Formation.

Yields of 0.1 to 0.4 L/s (1 to 5 igpm) are predicted from thin and usually silty drift in the eastern and northern zones of the plains part of the area, and on the milder slopes of the Caribou Mountains; from thin valley-fills from some valleys in the Caribou Mountains; from more isolated blocks and partially eroded beds of Dunvegan sandstones in the eastern and northern margins of the Caribou Mountains; and from deep-lying sandstone beds of the Bluesky Formations in small, driftless areas at the Hay River. A yield of less than 0.1 L/s (1 igpm) is predicted for the steep northern slopes of the Caribou Mountains, where thin, silty drift covers shale bedrock of the Shaftesbury and Hay River Formations.

The Devonian limestones are not color coded on the profiles. Yields from these limestones vary so much they cannot be characterized without detailed study. Unfractured old limestones can be virtually without effective porosity and could have yields of less than 0.1 L/s (1 igpm). Fractured limestones, especially if the joints are expanded by solution (karstic limestones), might yield enormous quantities of water (thousands of L/s). An area south from the map area (NE ¼ of Sec 29, Tp 108, R 13, W5th Mer) was tested by Tokarsky (1972) and a 20-year safe yield in excess of 30 L/s (400 igpm) was calculated. An observation hole, however, drilled only 10 m (30 ft) from the pumped well, yielded less than 0.1 L/s (1 igpm). In the north-central part of the area, Devonian limestones may be considered potential aquifers.

The Hay River, Loon River, Shaftesbury, and Smoky units have shale lithologies and have 20-year safe yields of less than 0.1 L/s (1 igpm).

Although it is quite thin, the Bluesky-Gething Formation contains some sandstones and locally may be a practical aquifer. The electric logs show it, however, to be usually silty and interbedded with shale. A 20-year safe yield of 0.1 to 0.4 L/s (1 to 5 igpm) is predicted for this formation, as an average for the area.

The Dunvegan Formation, the only major bedrock aquifer in the area, is about 125 m (400 ft) thick and contains abundant sandstone beds. The fine-grained sandstone, however, has little porosity and is interbedded with hard calcareous beds and

shale. The subcrop belt of the Dunvegan Formation around the Caribou Mountains does not show signs of high discharge to the surface. Based on these factors and on a comparison to observations at other places in northern Alberta, a yield of 0.4 to 2 L/s (5 to 25 igpm) is predicted for the Dunvegan Formation where it is continuous and of full thickness (see profiles B-B' and D-D'); otherwise, yields are less.

HYDROGEOLOGICAL PROFILES

Four hydrogeological profiles were constructed. The horizontal scale is 1:500 000; the vertical scale is 1:12 192 (1 mm to 40 ft, or about 12.2 m). Vertical exaggeration is, therefore, about 40 times. The profiles show the 20-year safe yield of the important rock units without distinguishing the individual aquifers. The main map, which is color coded, shows the sum of the yields of the formation in the upper 300 m (1000 ft). Because of the logarithmic scale of the yield categories (refer to map legend), these essentially delimit the highest-ranked formation.

Stratigraphy, generalized aquifer lithology, generalized flow directions, groundwater chemistry, and important observation points (wells, springs, testholes) are shown on the profiles.

HYDROCHEMISTRY

A side map with a scale of 1:1 000 000 of the chemistry of the near-surface (mainly drift) groundwater and the surface waters that are fed by groundwater was constructed. The hydrogeological profiles show the variation in chemical composition in vertical and horizontal directions.

The flow regime in an area affects the chemistry of groundwater. As water infiltrates into the ground, it begins to dissolve soluble materials. This process is helped by CO_2, which the water picks up from the soil and the root zones of plants. Along the groundwater flowpath, the most soluble minerals are dissolved first; then, as time progresses, the less soluble minerals also come into solution. Calcium (Ca), then magnesium (Mg), usually dissolve early as bicarbonate ions form, while sodium (Na) keeps on entering into solution.

The quantity of bicarbonate anion (HCO_3^-) formed is limited for practical purposes by the amount of CO_2 the infiltrating water has first picked up. The absolute concentration of the other anions, sulfate (SO_4^{-2}) and chloride (Cl^-), if available, however, may increase at all points along the flowpath. Consequently, along the flowpath of the groundwater system, the quantity of the total dissolved solids (measured in milligrams per litre, mg/L) usually keeps on increasing while the chemical character changes from calcium bicarbonate towards calcium-magnesium bicarbonate. If the water remains underground for a longer period, the change continues towards sodium bicarbonate; if sulfate is available (which is the case for most of the area), the water becomes increasingly sulfatic. The common chloride minerals are very soluble in water and are already removed by relatively fast-flowing local or intermediate flow systems from their zone in the area.

The deep flow systems move very slowly; in some cases, their water changes only over long geological times. In some geological structures, groundwater may, for practical purposes, become trapped. The chemistry of deep groundwater (formation water) changes from a mixed cations, sulfate type towards the sodium-chloride (common salt) type. Pockets of stagnant groundwater between flow systems change their water slowly and have higher total dissolved solids content, and also higher sodium, sulfate, and chloride percentages than neighboring flow systems. Special local sedimentary environments may lead to special water chemistry. Some nitratic waters of very low total dissolved salt content in the area (perhaps with the presence of organic acids) are stored or move entirely in organic deposits (muskeg, peat). A pool at the site of a collapsed peat mound (Lsd 3, Sec 3, Tp 117, R 13, W5th Mer; 860 m = 2820 ft amsl), for instance, contained only 58 mg/L of dissolved salts and 53.7 percent of the anions were nitrate (NO_3^-): the laboratory pH was 3.9. If this nitratic water moves in other (non-organic) media, the other dissolved anions soon change the character of the water.

Some characteristic groundwater chemistries are shown in figure 2 on a modified Piper diagram and are listed in Table 1. Arrows on figure 2 mark idealized trends of chemical change. Note, howev-

er, that the samples represent different individual *flow systems*. Samples No. 1, 4, 5, and 6, were all collected from discharge points of their respective flow systems; sample No. 7 was collected from the backpond of a slump, see "Discharge features" subchapter. Sample No. 2 was taken from a stream, the Hay River, for sake of comparison.

Arrow A marks the trend common in local and intermediate flow systems: calcium bicarbonate→ calcium sulfate→ sodium sulfate. The characteristic type of water from deep formations in the area is a sodium chloride (common salt) brine (samples No. 8 and 10); a calcium chloride type is also known (sample No. 9). The trends of chemical change from calcium or mixed bicarbonatic, and sulfatic waters towards a sodium chloride type of water are marked by arrows B and B', respectively, on figure 2. The total dissolved solids content may be very high.

A formation water sample taken from Slave Point limestone (Lsd 15, Sec 8, Tp 117, R 1, W5th Mer, elevation 723 m = 2373 ft), 641 to 677 m below datum (Kelly bushing), contains 284 495 mg/L dissolved solids. The sodium chloride content ultimately originated from the sea water at the time the sedimentary material of the basin fill was deposited. The processes shaping the formation water chemistry were dilution by fresh water recharge, concentration by membrane filtration, NaCl gain from dissolved halite (the sodium chloride mineral), formation of new minerals, and cation exchange on clays (Hitchon *et al.*, 1971).

The Red Earth region, about 150 km (100 mi) south of the Steen River-Whitesand River area, was investigated by Tóth (1978), who found three hydrodynamic zones superimposed on each other. Cross-formational flow does exist throughout the entire profile, but pressure conditions, groundwater chemistry, recharge conditions, and hydrogeological history are different for each hydrodynamic zone. The water chemistry of the formation, represented on the profiles, make it reasonable to suppose that a similar situation may also exist in the Steen River-Whitesand River area.

Only the upper hydrodynamic zone (drift and Cretaceous formations) discharges groundwaters to the surface within the area; the basal zone

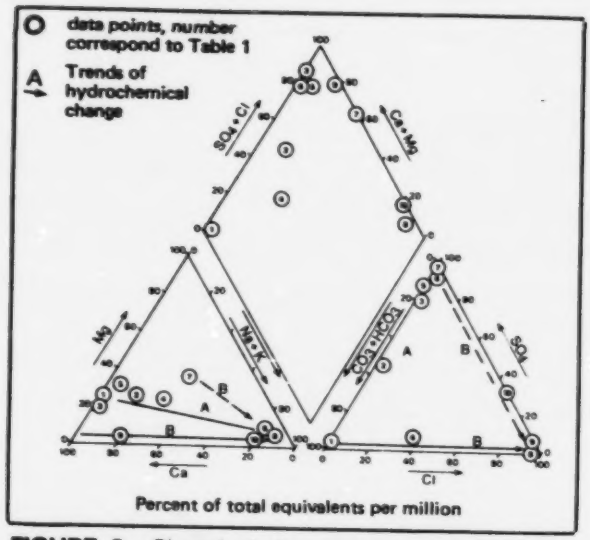

FIGURE 2. Chemical character of selected water samples, Steen River – Whitesand River area

(Beaverhill Lake limestone and deeper formations) does not. The middle zone (Bluesky sandstone, Wabamun, Winterburn, and Woodbend limestones) seems to be separate in the upland areas, but perhaps is not distinct from the upper zone in the lowlands.

These considerations explain the hydrochemical picture represented on the profiles and the map. Groundwater in local flow systems in drift are predominantly of a calcium bicarbonate type with low dissolved salts content: the symbols of this type cover most of the hydrochemistry side map. Local flow systems in shale (especially in slumped, weathered, loosened shale) discharge a calcium sulfate type of water of higher dissolved solids content around the Caribou Mountains and into its deep valleys. This sulfatic belt is quite visible on the map. Data from outside the map area make it likely that high sulfate groundwater is also present along stretches of the southeastern boundary of the area. These data came from shallow auger holes of less than about 3 m (10 ft) and likely are not representative of the more porous sections of the drift (Tokarsky, 1972).

CONCLUSIONS

The best aquifers of the area are in the drift. The buried channel area of the Cameron Hills has an

TABLE 1. List of water samples shown on Figure 2

Serial No.	Location Lsd	Sec	Tp	R	Mer (W of)	Elevation of surface m (ft) amsl	Sampled interval, m (ft) below surface	Geological symbol	Sampled formation and its lithology	Origin of sample	Total dissolved solids, mg/L	Chemical type
1	13	31	117	13	5	777 (2,250)	surface	Q	drift; terrace gravel	spring	146	Ca/HCO_3
2	7	22	125	18	5	293 (960)	surface	-	-	stream (Hay River)	224	$Ca\text{-}Mg/HCO_3\text{-}SO_4$
3	10	30	122	22	5	701 (2,300)	surface	Q	drift; sand, silt and gravel	dugout	430	Ca/SO_4
4	8	4	126	8	5	311 (1,020)	surface	Q	drift; ground moraine till	spring	210	$Ca\text{-}Na/HCO_3\text{-}Cl$
5	15	28	115	10	5	817 (2,680)	surface	K_s	Smoky shale, overlain by Holocene peat	slump	208	Ca/SO_4
6	5	7	103	12	5	640 (2,100)	surface	K_d	Dunvegan siltstone	spring	9,728	Na/SO_4
7	8	23	122	6	5	610 (2,000)	surface	K_{sh}	Shatesbury shale	slump	6,438	m/SO_4
8	10	4	113	3	5	338 (1,110)	214-227 (702-746)	K_{bs}	Bluesky sandstone	structure testhole	30,930	Na/Cl
9	8	17	120	1	5	440 (1,442)	312-328 (1,025-1,075)	D_{bl}	Beaverhill Lake limestone	structure testhole	23,630	Ca/Cl
10	11	10	117	12	5	853 (2,798)	613-628 (2,012-2,059)	D_{wd}	Woodbend limestone	structure testhole	14,815	Na/Cl

Remarks:
The serial numbers agree with those on figure 2.
Sample locations No. 6 and 8 are outside the map area.
The geological symbols are those shown on the hydrogeological profiles.
Chemical symbols: Ca = calcium; Mg = magnesium; Na = sodium; m = mixed (neither cation 40%); HCO_3 = bicarbonate; SO_4 = sulfate; Cl = chloride

estimated yield of 8 to 38 L/s (100 to 500 igpm). The yields of the sand and gravel deposits of the thick drift profile of the Cameron Hills and the terrace gravels along the Hay River are predicted to be 2 to 8 L/s (25 to 100 igpm). Drift is thinner in the remaining part of the area so yields are predicted to be 0.4 to 2 L/s (5 to 25 igpm) in the western half, and 0.1 to 0.4 L/s (1 to 5 igpm) in the eastern half of the area.

The bedrock formations are not promising in the area. The Hay River, Loon River, Shaftesbury, and Smoky shales are likely to produce less than 0.1 L/s (1 igpm). Along the steep slopes of the Caribou Mountains, the Shaftesbury shales subcrop under thin drift or outcrop in slumps and the predicted yield of the entire 300 m (1000 ft) thick upper rock is less than 0.1 L/s (1 igpm). The yield of the Devonian limestones is unknown; however, in neighboring areas, it is extremely capricious. Only in the north-central part of the area, where the Devonian limestones are covered only by thin drift and are likely weathered and karstic to a degree, can the limestones be considered prospective practical aquifers. The Bluesky-Gething sandstones have an estimated 20-year safe yield of 0.1 to 0.4 L/s (1 to 5 igpm). The predicted yield of the thicker but areally more limited Dunvegan sandstones in the main plateau of the Caribou Mountains is 0.4 to 2 L/s (5 to 25 igpm).

The quality of the shallow groundwater is good over most of the area, contains less than 500 mg/L dissolved solids, and is a calcium bicarbonate type. At some places, the shallow groundwater may even be too soft to drink. Along the steep slopes and deep valleys of the Caribou Mountains and in some areas in the southwest, the groundwater may contain several thousand ppm of dissolved salts and have a calcium sulfate character. The high sulfate content in the Caribou Mountains may be generated locally in the weathered, regionally

slumping dark shales. Groundwater at greater depth is of inferior quality and is a calcium or sodium sulfate or sodium chloride type with a very high (up to nearly 300 000 mg/L) dissolved salt content.

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MAPS NOT

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